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ACOUSTICAL EMISSION IN NONDESTRUCTIVE INSPECTION

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ABSTRACT: The development of procedures for using acoustical emissions for nondestructive testing is investigated. The phenomenon of acoustical emission is described and a theoretical model which explains the experimental data is given. The methods for detecting fractures and deformation in materials is described. Examples of the analysis of fractures and the determination of critical loads for structures is included.
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1.00 INTRODUCTION

Knowledge concerning various types of nondestructive tests is widespread. However, due to the ever-increasing necessity for highly accurate results in tests of that sort in specific inspections, new nondestructive methods are being developed that are linked to factors of time and economics. Obviously, some are better known than others, but the fact remains that in general they are still in their infancy; however, it is no less true that the results attained allow us to foresee future potentials of nondestructive tests. Within that scheme of ideas, the main purpose of the present work is to have it placed, as indicated in the above title, within "acoustic emission," one of the new nondestructive tests, the objective of study conducted by hundreds of researchers. In view of the complexity of the phenomena, it will be treated in the most comprehensive way possible, even going to the extent of endeavoring to use a common terminology, which is quite difficult because, as in the case of all new fields of technology, studies conducted independently evolve variations in terminology, sometimes even causing confusion until such time as the techniques are universally standardized for the common interest.

2.00 DESCRIPTION OF THE PHENOMENA

Acoustic emission is a wave produced by the mechanisms of fracture and deformity that take place within the materials due to localized forces. As the resulting wave is elastic by nature, it propagates itself throughout the material and can be detained at the material's surface and converted into electrical signals by means of piezoelectric sensors. This synthesis serves as the basis for the adaptation of the phenomena to the nondestructive test.

Thus, when a metal is subjected to a charge it emits sounds (that is, the phenomena of acoustic emission) brought about by processes due to permanent deformities, such as dislocations, shifts, formation of microfissures, etc. Such deformities produce "continuous" signals of acoustic emission which are more indicative of defective material.

On the other hand, a certain "noncontinuous" signal is the fundamental basis of characterization of the progress of a defect within the material receiving the charge.

For example, in steel the "continuous" signals appear with a mean frequency of 5 kHz, accompanied by sporadic "noncontinuous" signals of 20 kHz, for a material suffering only from deformity. Acoustic emission is observed in ductile fractures of steel samples in the range of 40 to 50 kHz. Brittle fractures produce "noncontinuous" signals of frequencies above 200 kHz.

All of these signals are recorded on magnetic tape by piezoelectric transducers for subsequent interpretation, which include location of the defect, appraisal of its size as well as an estimate of its speed of propagation, which in most instances consists of a crack. Meanwhile, all of these signals are recorded mixed in with signals of interference, which can be confused as coming from acoustic emissions from assumed defects. For example, in tubing with high pressure and temperature, the study of propagation of cracks is severely impaired by the processes of cavitation, ebullience and turbulence of the fluids which are practically within the same frequency range of acoustic emission that is being sought. The alternative found.was to work at higher frequencies and the adaptation of sonar filters and this brought success because the acoustic emission showed that it contained components of up to 2 MHa, when necessary.

3.00 PRIMARY OBJECTIVE AS NONDESTRUCTIVE TEST

The first idea having been launched with the example of steel we should reveal that to the first idea was added the feature of number of counts of acoustic emission per unit of time, which completed the primary objective of the nondestructive test for differentiating between materials that are defective and those that are not. Thus, the main differences are:

1) Increase of the rate of acoustic emission with the increase of the charge, which is far greater for materials with defects than for materials without defects.

2) Cracked materials always indicate that the acoustic emission shows up for charges very low compared to a charge of weakness of the same. On the other hand, normal materials have an emission which initially is close to the charge of weakness.

3) Cracked materials produce signals with a wide range of "noncontinuity," while normal materials are characterized by emitting "continuous" signals and they only contribute with "noncontinuous" signals a little before the charge brought about by the fracture.

4) It is possible to calculate the position of the defect and subsequently locate it by triangulation and to utilize multiple transducers. Experience shows that the speed of propagation of the elastic waves of acoustic emission is slightly less than the theoretical speed of the transversal waves.

Figure I illustrates the process of triangulation where, by means of knowledge of the corresponding periods of time for transducer-defects and establishment of speed of propagation, one obtains the distances produced. For each transducer the distance is obviously the geometric place of the equidistant points, which is a circumference. The intersection of the geometric tracings provides the location of the defect.

4.00 ANALYSIS OF FRACTURES

Once the possibility of identification of defective areas has been delineated, as well as their location in a first stage, the following stage is still more complex, consistent with the estimate of fracture charge, size and characteristics of the defect by means of a possible dependence of all these imponderables on the acoustic emission.

It was stated that metals show the phenomena of acoustic emission when subjected to the charge due to deformities. Now we should state that such deformities are processes subjected to plasticity which emit elastic waves when given a charge a little before attaining the point of weakness, or that is, this occurs because certain areas attain such points due to the concentration of tensions in those same areas. Within this frame of ideas, a crack would provide such a concentration of tension and the acoustic emission characteristic would begin well below the general point of weakness of the material.

This being the case, it was appropriate to introduce a unique parameter, K, called the factor of tension intensity which controls the tension in the proximity of the extremity of an elastic crack. Such parameter depends on the body's geometry, shape, and type of charge present. This is known for a great variety of geometric shapes and around them are found directly or indirectly the estimates concerning a fracture. In general if

$$K = C \cdot a^{1/2}$$

where, C = constant for a given tension and geometric shape

a = size of the crack.

Theoretically, many models have been tried out for the purpose of predicting a relationship between the total number of emissions observed (N) and the tension intensity factor (K).

One of these models is supported by various hypotheses, among which the following are fundamental:

a) The acoustic emissions per unit of time ($\dot{N}$) attain the maximum in the proximity of the point of weakness. See Figure II-A.

b) The size of the plastically deformed area is given by

$$R = \frac{1}{2\pi\,(K/\sigma_e)^2}$$

where,

σ_e = material's tension weakness.

See Figure II-B.

c) Once the emission occurs principally due to the material's plastic deformity, then it is assumed that $\dot{N}$ is proportionate to the material's increase in volume in the plastic area per unit of time ($\dot{V}_p$), or that is

$$\dot{N} \propto \dot{V}_p \,.$$

From these two fundamental hypotheses an appraisal of V_p provides,

$$V_p \propto K^4$$

and finally from the latter it turns out that

$$N \propto K^4.$$

The latter equation indicates that at any instant the total sum of counts will be proportionate to the fourth power of the tension intensity factor present for the defect at that same instant.

In practice it has been observed that $N \alpha K^s$, with the exponent s varying from 4 to 8.

A characteristic example can be seen in Figure III-A, for four samples of aluminum, with variable cracks. At the same time Figure III-B illustrates those same samples in the function of an applied charge. These two experimental items of data give evidence of linear dependence between K and the applied charge F. The shape of the two sketches shows clearly that relationship, and then we have,

$$K \alpha F.$$

The results suggest a sequence for appraisal of the fracture charge and sizes of defects in complex structures. Such a sequence would be:

1) draw up graphs N-K for the material being examined from samples containing defects of known geometric defects. The critical tension intensity factor (K_c) would be determined by making the specimens break;
2) the structure being under an arbitrary but sufficient charge (F_t) would provide knowledge of N_t, which would be measured;
3) the corresponding value K_t would be obtained from the graph of the first item in that sequence;
4) given the linear dependence, $K \alpha F$, then one would estimate the fracture charge or critical charge, F_c, by means of the equation

$$\frac{F_t}{K_t} = \frac{F_c}{K_c} ;$$

F_c would then be the critical charge supported by the structure;
5) an estimate of the size of the defect would be obtained through the equation $K = C \cdot a^{1/2}$, where C would be defined by the samples shown in the first item.

Figure IV illustrates the sequence delineated above.

If there were several defects present in the structure, one would obtain the number of counts above and the tension intensity factor would favor the greater defects.

5.00 OTHER APPLICATIONS

Figure V illustrates the results of tests conducted on cracks produced by weakness of the steel due to hydrogen, and where the sum of the counts would provide in this case the area of the defect. Such facts and graphs could be drawn up in the sequence of the preceding item.

Another typical case of application would be the examination of the soldered areas which present the greatest advantages for inspection when conducted during the soldering process, which does not occur with the rest of the tests, which are effected after completion of the same. Such advantage is due to the fact that the elastic waves of acoustic emission can be detected at a good distance from the soldered area. In sum, the problem bears the following characteristics:

1) The acoustic emission is produced by the formation of cracks and their growth. There are strong indications that porosity produces (obliterated word) acoustic emission.
2) The amount of acoustic emission observed may be related to the size and number of defects.
3) As stated initially, there exists interference of similar emissions coming from the soldering's make-up.
4) The above signals can be differentiated by filtering techniques.
5) Signals are strongly observed, even in soldered areas with cracks undetected by means of radiography.

Figure VI illustrates a possible relationship between the size of the cracks and the total emission, in an investigation conducted concerning the inspection of surface solderings.

Other examples could be cited, including the structures of airplanes against fatigue cracks; studies of the mechanisms of fractures in metals and nonmetals; penetration of micrometeorites in space vehicles; nuclear reactor inspections, etc.

6.00 CONCLUSIONS

It can be concluded that acoustic emission evidently does not involve a routine technique and that there still remains a lot to be done; but, despite its infancy, for certain specific cases it proves itself to be a very potential tool.

Given the complexity of the phenomena, certain parameters have yet to be better interrelated and better explained so that such techniques, with great possibilities, may be standardized. On the other hand, we should stress that we are not trying to present details concerning acoustic emission and it became possible to obtain a sequence, which in reality does not exist because of the different paths followed by the researchers. This being the case, the main objective was to give a bird's-eye view of the process and to point out that like acoustic emission, other nondestructive tests will take the place of those traditionally used, especially for specific cases, which evidently cannot be predicted for some time to come.

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